NATIONAL BUREAU OF STANDARDS REPORT

7008

VELOCITY MEASUREMENTS WITHIN AND NEAR FLAMES BY IMPACT TUBE TECHNIQUES

By

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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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ABSTRACT

A brief investigation is described during which various problems related to the use of impact pressure methods for determination of gas flow velocities in and near flames were studied. It was found necessary to reduce as far as possible the length of the impact tube in the vertical direction when the flowing gas temperature differs significantly from that of the ambient. Some data are included on velocity head and temperature profiles in the region above a small fire involving normal heptane floating on water in a dish of 7 cm diameter.

1. INTRODUCTION

When burning various test models, it is frequently desirable to know the velocity distribution of the inrushing and outgoing gases. One method of determining these velocities is to make pressure and temperature measurements and from these data calculate the velocity from the Bernoulli relationship. However, since the velocity heads encountered in the gases from flames are so small, special refined methods must be used in measuring them. This report describes a brief study of the various methods, apparatus, and problems associated with making such low pressure measurements.

2. APPARATUS

The apparatus used included impact tubes and a micromanometer (Fig. 1) capable of measuring pressure differences to 1 or 2 x 10^{-4} in. of an alcohol manometer fluid.

3. EXPERIMENTAL RESULTS

Preliminary pressure tests were run by burning n-Heptane, $CH_3(CH_2)_5CH_3$, floating on water in a glass dish of 7 cm diameter. A thermocouple formed of 0.013-in. diameter chromel alumel wires was connected to the end of the impact probe to measure the temperature of the gases. Longitudinal and cross sectional pressure and temperature plots were made (graphs 1, 2). The data were rather scattered since the flame was unstable and fluctuated considerably; however, results seemed quite useful to indicate the general trends. If further results are desired along these lines, special precautions to increase flame stability will almost certainly lead to better data; the purpose of my experiments was primarily to test the limits of the apparatus, so time was not spent trying to design a method to insure a stable flame.

After a few measurements of this type, another problem was noted. It was found that pressure measurements taken at identical positions in the flame differed considerably if probes with different stack lengths exposed to high temperature, measured in the vertical direction, were used; a probe with a longer stack length would record a higher pressure than one with a shorter stack. This effect was investigated further by performing an experiment in which pressures were measured at a certain point using probes with different stack lengths. Stack length was measured as shown in Figure 2.

The results (graph 3) show that the pressure increases directly with stack length. Also, the slope of the linear relationship changes with change in position of the probes (probably due to the change in temperature at the different positions). This effect is attributed to differences in density of the heated gas within the tube when compared with density of ambient air.

From the above results, it was concluded that a probe with as short a stack as possible would be required to obtain accurate results. The impact tube finally adopted is shown in Figure 3. The previously reported data were obtained with probes having a stack length of 5/8 in. Because of this a slight negative pressure correction is applicable to these data.

This tube was checked in air streams of known velocity and was found to have a unit coefficient. It was also found to be relatively insensitive to deviations of the direction of gas flow up to about 15°. With this probe, the increase in pressure due to the stack effect would probably not be greater than 1×10^{-4} in. of manometer fluid. Of course, when using the probe in hot gases, it must be oriented so that the long arm is horizontal, otherwise a stack effect may be introduced in the arm itself.

Another source of error resulted from the fact that the pressure differences measured were very small, so that a slight inaccuracy in making a measurement resulted in a large percentage error in the final result. As an example, suppose that for a pressure difference of 30×10^{-4} in. of manometer fluid, there was an inaccuracy of 2×10^{-4} in. in the measurement (this can be considered as good accuracy); the percentage error is then 6.67%. In order to get better accuracy special precautions must be taken. It was found that lighting was very important; with improper lighting the periphery of the meniscus may be difficult to see. A flashlight placed above and to the right illuminating the hairline from about three feet away resulted in a dark meniscus on a light background which was very easy to distinguish. Care must also be taken to assure that the hairline is accurately zeroed on the meniscus, since a movement of 1×10^{-4} in. is difficult to observe. These precautions plus the large time constant of the manometer involves a considerable amount of time for each reading. It was also noted that the zero position would drift as flame tests were made. This effect was attributed to temperature and thus volume changes of the manometer fluid caused by heating of the enclosing cabinet. To obliviate this effect is was found advisable to have a radiant shield such as aluminum foil between the manometer cabinet and the heat source. Backlash in the mechanical system was eliminated by always turning the micrometer screw in a constant direction when making measurements.

4. GAS VELOCITY COMPUTATIONS

The method of computing gas velocities from pitot tube measurements may be illustrated by reference to Figure 4 and the following development:

From Bernoulli, at any two points in a horizontal flowing stream:

$$p_1 + 1/2\ \rho v_1^2 = p_2 + 1/2\ \rho v_2^2.$$

Considering points A and B, and since the velocity at A is zero,

$$(p_v + p_s) = p_s + 1/2\ \rho_g v^2$$

or $$v^2 = 2p_v/\rho_g. \qquad (1)$$

Now, considering the manometer displacement

$$p_v + p_s = p_s + \rho_m gh$$

or $$p_v = \rho_m gh. \qquad (2)$$

Substituting (2) in (1) and solving for the gas velocity

$$v = \sqrt{2gh\ \rho_m/\rho_g}$$

Using units commonly employed

$$v = \sqrt{2 \times 32.2\ \text{ft/sec}^2 \times 12\ \text{in/ft} \times \rho_m/\rho_g \times h}$$

$$= 27.8\sqrt{(\rho_m/\rho_g)\,h}\ \text{in/se} = 139\sqrt{(\rho_m/\rho_g)\,h\ (\text{in.})}\ \frac{\text{ft}}{\text{min}}$$

$$= 139\sqrt{(\rho_m/\rho_g)\,h}\ \frac{\text{ft}}{\text{min}}$$ where h is measured in inches

It should be noted that since points A and B are not in a horizontal plane, a correction is required for the previously described stack effect. Because of this, it has seemed impractical to use pitot tubes for flame velocity measurements without suitable stack effect corrections. However, where lengthy tubes are necessary between the sensing device and manometer, there appears to be a distinct advantage to the use of a pitot tube, provided the tubing pair are taped together so that the stack effects will be balanced out. In such an arrangement the only correction required will result from differences in elevation of the static and impact openings of the pitot. With flames of the size studied, the static pressure within

the flame appears to be very close to that of the ambient atmosphere. Thus, it is permissible to use an impact tube alone as has been previously described.

One difficulty which has not yet been solved is the determination of the composition of the hot gasses. Both composition and temperature of these must be known so that density can be determined for velocity computations.

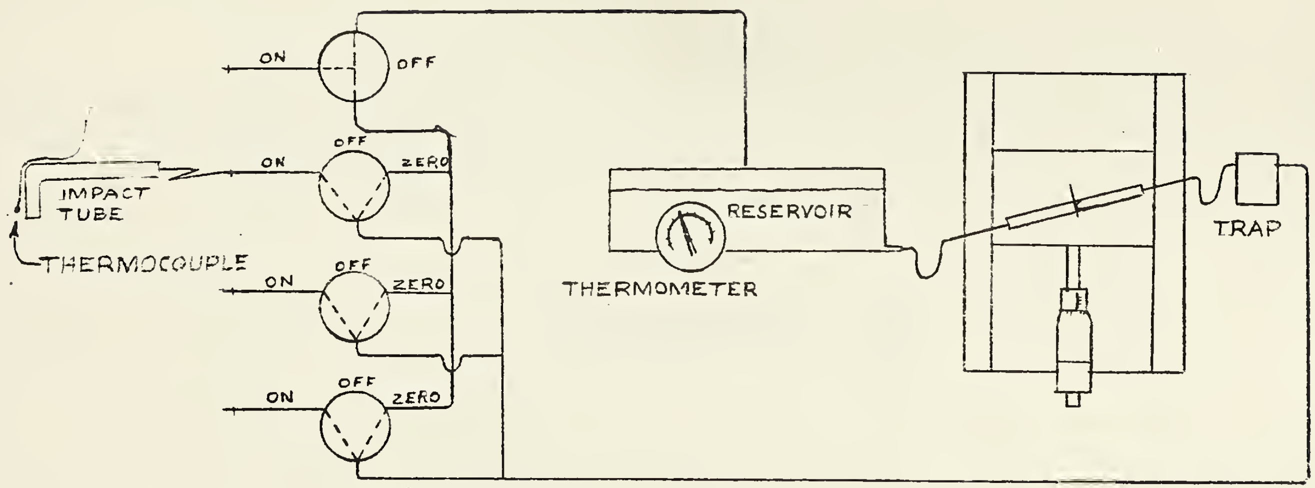
Table 1 presents the results of a series of computations for purpose of determining the extent to which computed velocities will be dependent on the assumed combustion product composition. It is evident from this table that wide changes in gas composition result in significant but not major changes in computed velocities. Since in most instances it will be possible to predict with considerable accuracy, either on the basis of gas analysis or from considerations of the fuel being burned, the composition of the flowing gas, it seems likely that considerable confidence can be placed on velocities computed in this manner.

TABLE I

Variation in Computed Gas Velocity Resulting from Variations of Flowing Gas Compositions

This table presents the gas stream velocity computed on the basis of a gas temperature of 800°C, pressure of 760mm Hg. and a manometer unbalance of 1 X 10^{-3} in. of alcohol. Velocity deviation is reported with reference to that of air.

Gas	Velocity	Velocity Deviation
	ft/min	%
Air	218	-
N_2	222	1.8
CO_2	176	18.9
CO	222	1.8
H_2O	276	26.2



Micromanometer Schematic

FIGURE 1

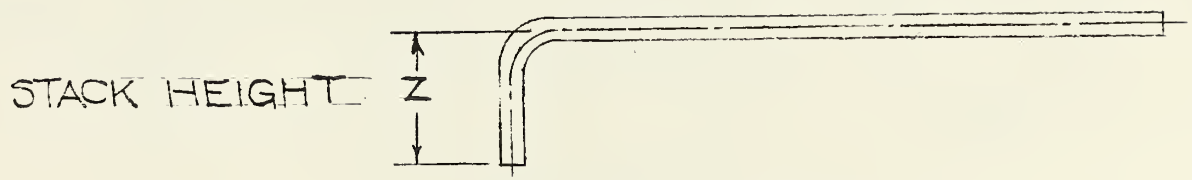


FIGURE 2

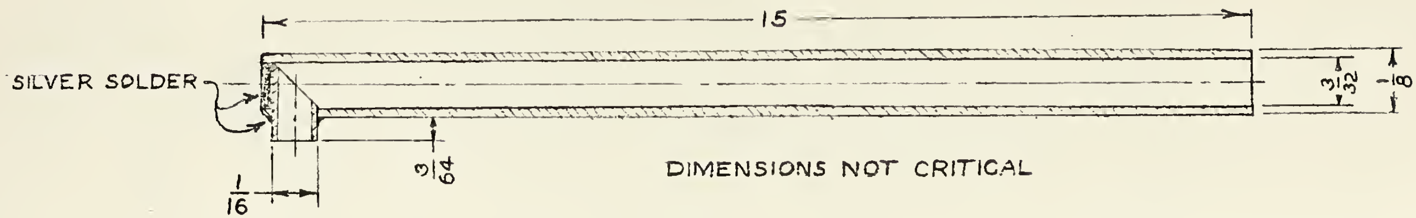


FIGURE 3

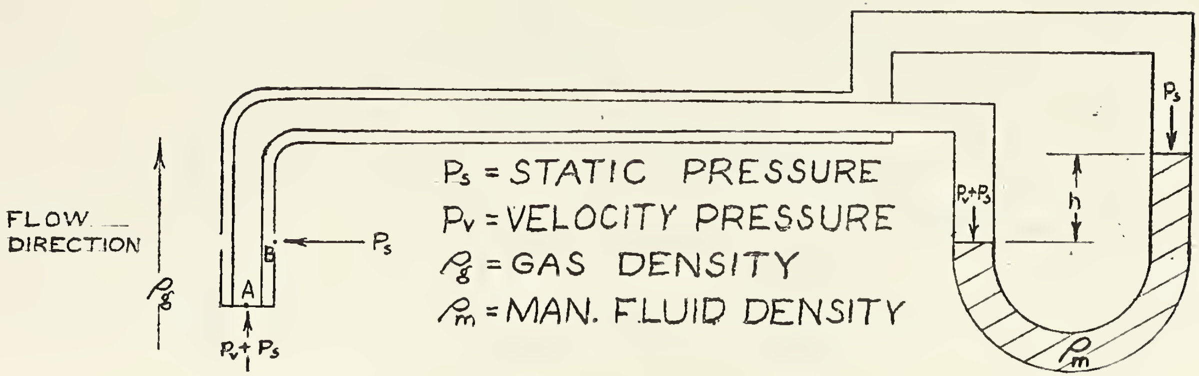
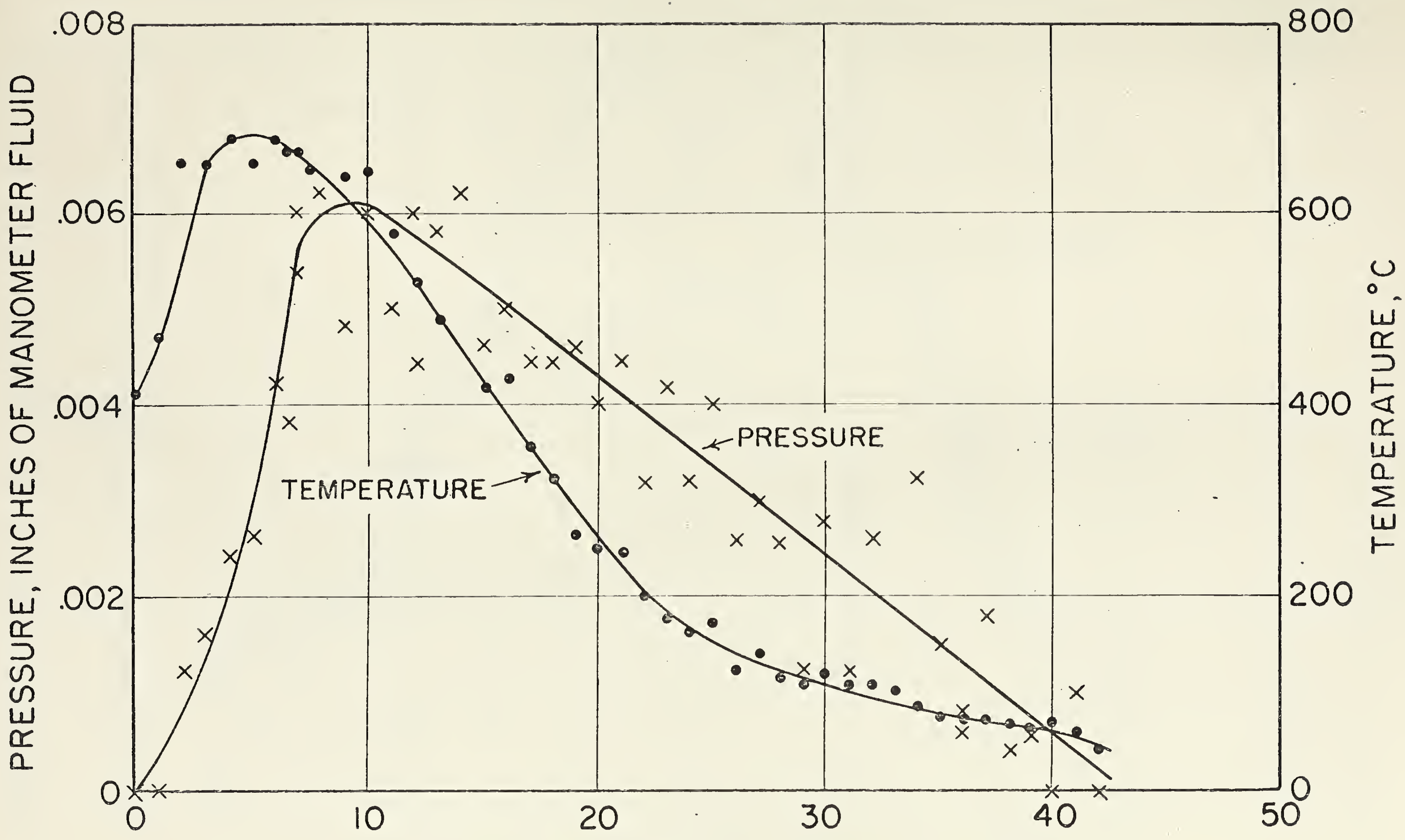
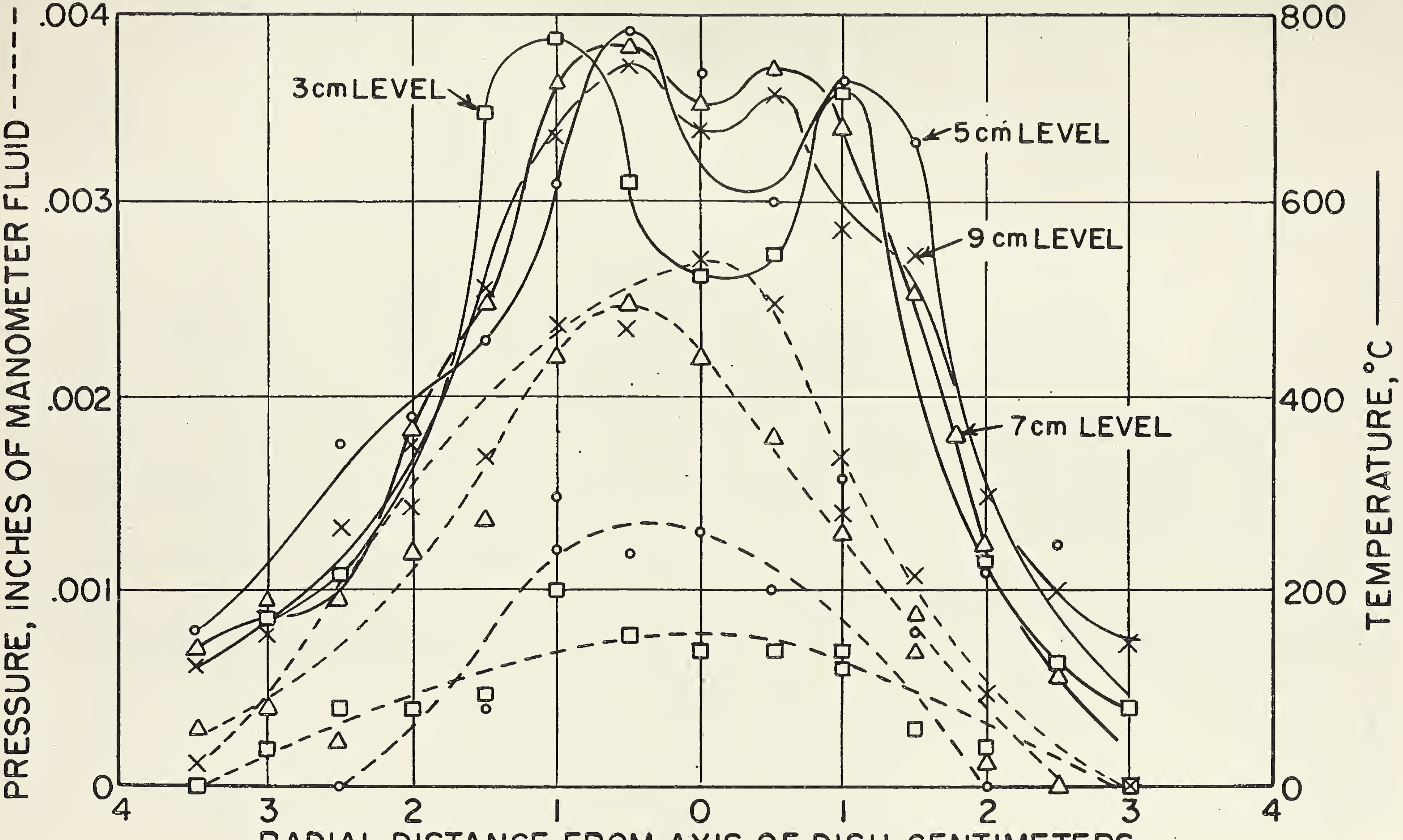


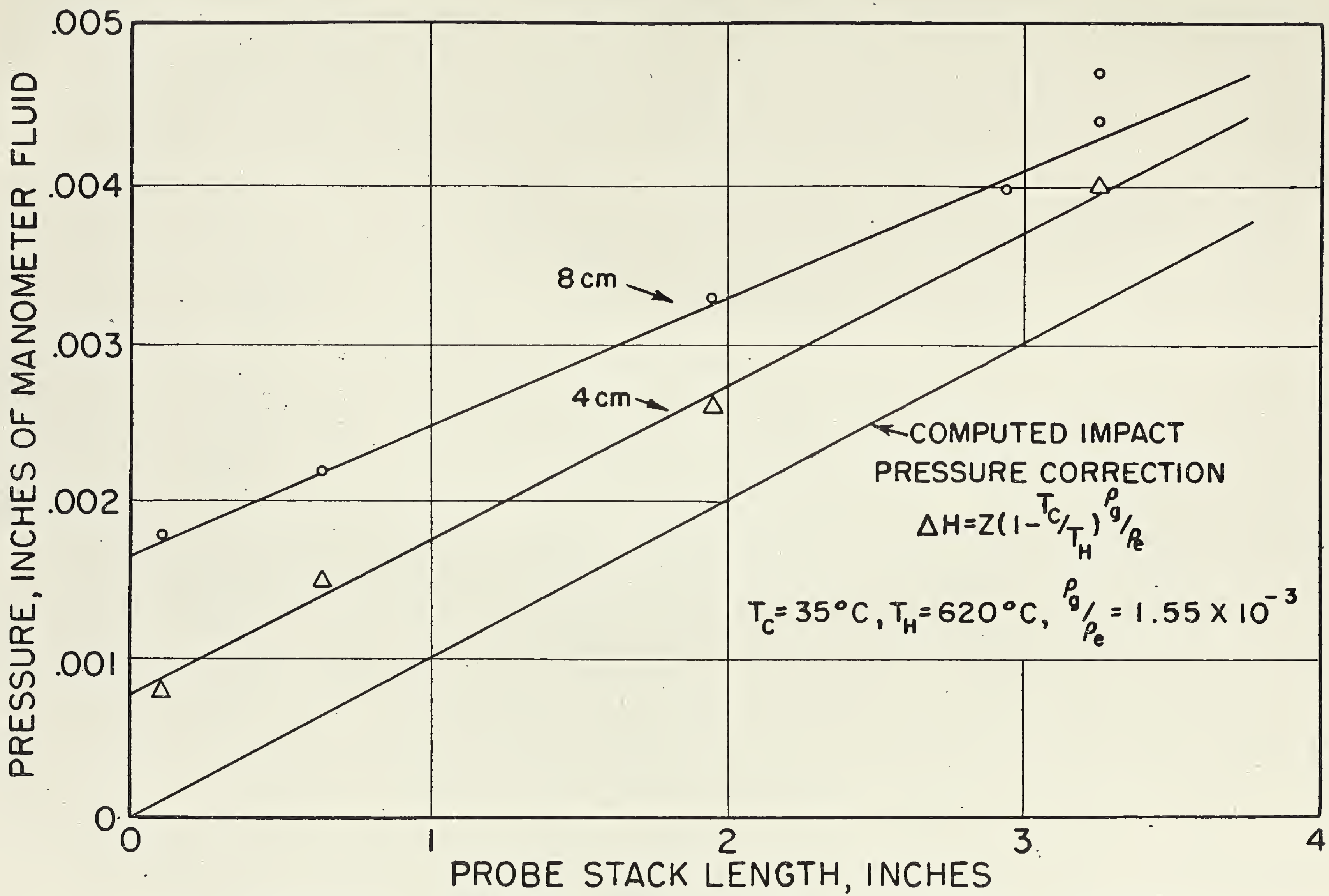
FIGURE 4



GRAPH I.- THERMOCOUPLE TEMPERATURE AND IMPACT PRESSURE ON THE AXIS OF A n-HEPTANE DIFFUSION FIRE



GRAPH 2.-THERMOCOUPLE TEMPERATURE AND IMPACT PRESSURE AT DIFFERENT ELEVATIONS ABOVE A n-HEPTANE DIFFUSION FIRE



GRAPH 3.- IMPACT PRESSURE VS. PROBE LENGTH
ABOVE A n-HEPTANE DIFFUSION FIRE

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Office of Weights and Measures.

BOULDER, COLO.

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